COMPUTER-ASSISTED ANALYSIS OF DENTAL CROWDING AND ITS RELATIONSHIP TO TOOTH SIZE, ARCH DIMENSION, AND ARCH FORM IN THE MIXED DENTITION, UTILIZING THE APPLE II PERSONAL COMPUTER

by

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INTRODUCTION

The role of the personal computer in dentistry is expanding. The prediction has been made that within the next ten years about 90 percent of dental practices will have a in-house computer system.[1] The computer is finding clinical chairside application.[2-5] However, Zimmerman et al.[6] reported in a recent survey that less than five percent of dentists utilizing computers in the office do so for diagnostic help or for design of treatment protocols. They concluded that "If dentists are to be encouraged to vary their (computer) applications, there needs to be more continuing education programs, additional training, and <u>increased software programs</u>." Software programs are of first importance, as they determine what the computer can do.[1,7] The versatility of the personal computer depends on the availability of a variety of software programs specifically developed for dentistry, without which computers will have little impact on dental care.

One of the primary goals in the treatment of children and young adults must be the preservation and management of the integrity of the dental arches through their transition from the primary dentition to the permanent dentition.[8] Appropriate treatment of children involves more than the traditional role of caries control and prevention; it must include preservation of arch length to minimize dental crowding and entrapment of the erupting permanent teeth. Cast analysis is required for all potential pediatric-orthodontic patients, whether the crowding problem is moderate or severe.[9] It is here that the computer can aid in chairside dental diagnosis by applying its enormous power of data manipulation to aid in the calculation of available dental arch length.

The focus of this study was mixed dentition analysis, specifically the application of computer technology to that analysis. First to be investigated was the possibility of designing a prototype "user-friendly" microcomputer program to assist in the diagnosis of space analysis in the mixed dentition. The utility of such a program would include time savings in performing the analysis, an increased accuracy of mathematical calculations, and the ease of production of a permanent record.

Having established the reliability of the prototype program, a second microcomputer program was used to examine dental crowding and its relationship to tooth size, arch dimension, and shape. Selection of an appropriate treatment approach depends on which factors influence the dental crowding. The stage of the mixed dentition constitutes the most intricate period of the development of the occlusion; any small anomaly present in this stage can carry complicated problems to the permanent dentition.

REVIEW OF LITERATURE

COMPUTER-ASSISTED DENTAL DIAGNOSIS

The personal computer can vastly supplement the delivery of dental care. It is a powerful tool that can perform functions pertaining to patient registration, family billing, appointment and recall scheduling, processing insurance forms, general accounting ledger, inventory, word processing, and diagnosis and treatment planning.[7] Computer usage in the dental office is limited only by the innovation of the dentist.

Within the next ten years about 90 percent of dental practices will have an in-house computer system.[1] Computer applications in dental practice will save 75 percent of the time required to do the same tasks manually, allowing dentists to spend more time in patient care and diagnosis and less time on the routine daily business aspects of their practices.[10,11] The computer is finding clinical chairside application.[2-5] However, a need exists for the development of diagnostic dental software for the microcomputer. Snyder and Felmeister[12,13] reviewed 39 commercial software programs developed for the dental profession. Only one program had clinical application to chairside diagnosis and treatment planning; all other programs that were reviewed were designed as office management systems.

Computer program applications have encompassed standardized patient charting[14,15] as well as the storage and analysis of data in many phases of dental research.[16-23] Diagnostic software applications have primarily focused on orthodontic diagnosis.[24-33] Since the personal computer is a machine that follows software programs, it is the variety of available programs that provides for the computer's great versatility. Thus, software programs are of first importance inasmuch as they determine what the computer can do.[1,7]

Although computer-assisted diagnostic systems currently offer advisory assistance, the scope of the assistance is variable and dependent on the system utilized, the user, and the diagnostic problem.[16-34] A computerized diagnostic system could be considered a focal point capable of being modified by the incorporation of other software programs, such as instructional routines. With the development of an instructional routine, a computer-assisted diagnostic system could assist in the instruction and education of the patient as well as in continuing education for dentists.[34]

Computer-assisted model analysis in the diagnosis of arch length adequacy in the mixed dentition has essentially been unavailable to the practitioner because of the expense of the larger computer systems found in institutions such as research centers and universities.[35] However, the personal computer has become small, powerful, and inexpensive, with the result that computer-assisted diagnosis applications are becoming more available to the practitioner.[36] Many published methods of dental arch analysis and computer programs involve the electronic digitalization of points on occlusal photographs.[35,37-39] Digitalization of study models has been performed accurately without the intermediate stage of photography or photocopying, utilizing direct digitalization of landmarks on the plaster cast.[40,41] Direct intraoral digitalization of landmarks has been undertaken with the use of fine-tipped electric calipers interfaced with the computer.[42] Programs are available to the practitioner which do not require the additional hardware of digitalizing boards or electric calipers, with data entered via the computer keyboard.[43]

Fundamental to the application of "computer-assisted diagnosis" is the logic and design of the computerized system. Computerized diagnostic processes can be classified as either logical, statistical, or mathematical.[44] Logical models typically utilize a series of questions or prompts, the answers to which direct the program logic flow through divergent pathways and end with a proposed diagnosis. The logical models can be represented by the classical decision tree, although there are many variations.[34] Statistical approaches form diagnoses by mathematical consideration of disease-symptom relationships and disease probabilities identified in sample populations. The three most common statistical approaches utilized are: (1) conditional probability based on Bayes theorem, (2) linear discriminant analysis, and (3) symptom profile or pattern matching.[36,44] For validation of a program utilizing either approach, the diagnosis produced is compared with the confirmed diagnosis.[34]

Although the diagnosis arrived at by the program developed in this protocol may be broadly classified as artificial intelligence, the approach uses numerical calculations rather than symbolic reasoning. The programming utilized in the analysis for this study, for the determination of unerupted succedaneous tooth size, is written in "Applesoft" BASIC (Beginner's All-purpose Symbolic Instruction

Code). The program utilizes a series of "IF-THEN" conditional statements in its probability table for the prediction of tooth size. The "IF-THEN" statement is a two-way branch construct that allows a program to branch based upon the true-false condition of some expression. The condition is tested, and if true the program branches one way, if false another way. Relational and Boolean expressions are most common with "IF-THEN" statements, but arithmetic expressions are utilized equally well. The "IF-THEN" statement gives a BASIC program real decision making capabilities.[45-47]

ARCH LENGTH DEVELOPMENT

Once the clinical findings of the hard and soft tissues are noted and charted, the practitioner's next step should be to determine the amount of available space, utilizing an arch length analysis.[48] Arch length should continue to be assessed until the permanent canines and premolars are to erupt, and plan treatment to assure that space will be available.[48] During this time the data manipulating power of the computer is most beneficial for the calculation of available space.

The purpose of any mixed dentition analysis is to evaluate the amount of available space in the dental arch for the alignment of the permanent dentition. The analysis is important in determining whether the treatment plan will involve serial extractions, eruption guidance, space maintenance, space regaining, or periodic observation of the patient.[49] The management of the developing dentition with interceptive orthodontic procedures requires an understanding of the growth changes occurring during this transition. The eruption of the first permanent molars marks the normal transition of the primary to the mixed dentition. The position of the first permanent molars establishes the natural limit of the available arch length for the alignment of the permanent teeth mesial to the permanent first molars. It is well-documented that available arch length is continually decreasing with age.[50]

A space discrepancy will develop if the available arch perimeter cannot accommodate the permanent dentition. Tooth size and alveolar size are the primary factors that determine the status of the permanent arch.[51] For many children, the eruption of the permanent incisors results in a crowding problem that attracts the attention of both parents and the children.[8]

The permanent incisors are normally substantially larger than the primary incisors they replace. The average person begins with a sizeable inherent space discrepancy in the anterior dentition.[52] However, not everyone has an obvious space inadequacy once all the permanent teeth erupt. There are several ways of overcoming this space discrepancy. Interdental spacing in the primary dentition is a common means of giving the permanent teeth more room to erupt. Interdental spacing can account for an average of four millimeters of space in the maxilla and three millimeters of space in the mandible.[8]

The permanent teeth erupt into a greater anterior arch diameter, or inclination, than the primary teeth occupied. This is not a result of growth of the arches, but of a more labial eruption position of the incisors and of increased intercanine distance.[8] However, a small amount of alveolar bone growth does occur to increase intercanine distance.[53]

An additional factor to consider in the transitional dentition is Nance's[54] "leeway space," which is defined as the difference between the total mesiodistal widths of the primary canine and molars and the total mesiodistal widths of the permanent canine and premolars. The average leeway space excess for each posterior mandibular segment is 1.7 millimeters, and 0.9 millimeter for the maxillary posterior segment.[54] However, in the mandibular arch, the leeway space is often used during the mesial migration of the permanent first molars into an Angle Class I dental relationship.[8] This molar shift can decrease any potential for overcoming the "incisor liability." Barber[55] states that the proper goal of treatment for the transitional dentition should be the prevention of arch length loss in any degree no matter how small.

A number of methods are available for determining arch length. Moyers,[56] Nance,[54] Hixon and Oldfather,[57] and Johnson and Tanaka[58] all have developed techniques for analysis. These methods of analysis are based on three strategies for predicting the size of the unerupted permanent canines and premolars: (1) a method of predicting tooth size from measurements of the radiographic image of the unerupted teeth;[54,59,60] (2) a method similar to Moyers' Analysis[56] based on the fact that one may measure a tooth or a group of teeth already erupted into the mouth, and thus predict accurately the size of the unerupted teeth[58,61,62] and (3) a method using a combination of measurements from erupted teeth and from radiographs of unerupted teeth.[57,63-66] This last approach is considered the most accurate, as it generally has the lowest standard error of measurement.[66,67] Prediction methods for the unerupted permanent teeth have been developed with simple regression analysis techniques,[56-58,60,63] multiple regression analysis,[64,66,67] and other approaches.[57,60,63] Foster and Wylis[59] stated that clinically the quality of the intraoral radiographic films should be the determining factor in the selection of one method over another. Predictions based on erupted incisor widths are more accurate than those using poor intraoral films, whereas films taken by a meticulous technique can provide more accurate predictions than those based on mathematical formulas.

Moyer's analysis was adapted and utilized in the development of this computer program because it has a number of advantages. This analysis has minimal systematic error, and the range of such errors is known on children whose genetic background is European. It can be used with equal reliability by the beginner or by the experienced clinician.[68] The analysis can be performed without the use of dental radiographs. It can be completed in the mouth as well as on dental casts. It can be used for both dental arches and for each posterior and anterior segment of the arch.[56]

The results of the mixed dentition analysis of space availability will be positive if enough space is available or negative if there is a space inadequacy. Arch length analysis is but one part of dental cast analysis in treatment planning. A complete analysis should also include examination of the skeletal and soft tissue patterns, the axial inclination of the incisors, vertical dimension in the anterior region, occlusal plane leveling, eruption sequence and timing.[69]

Accurately predicting the mesiodistal widths of the unerupted permanent canines and premolars in the mixed dentition can lead to orthodontic treatment that is optimally timed, with desirable facial and dental results.[64] The stage of the mixed dentition constitutes the most intricate period of the development of the occlusion; any small anomaly presented in this stage can carry complicated problems to the permanent dentition, requiring a more extensive and expensive mechanotherapy.[70]

DENTAL CROWDING AND ITS RELATIONSHIP TO TOOTH SIZE AND ARCH LENGTH

Theories to explain the cause of dental crowding encompass aspects of evolution, heredity, and environmental factors. Dental crowding may result from an evolutionary trend toward a reduced facial skeleton size without a corresponding reduction in tooth mesiodistal width.[71] Factors related to dietary changes have influenced the rate of dental evolution within *Homo sapiens*.[72] These factors include a switchover to a meat-eating diet, the use of tools in food preparation, and finally cooking.[73] Advanced populations that consume a diet composed largely of cooked meats and vegetables, as well as processed foods, do not require large chewing forces and teeth for survival. The dentition has taken a less dominant evolutionary role in individual survival and mate selection, compared to that of mammalian predators. The dentition has a small role in man's natural selection processes.

Brash[74] emphasized the effects of heredity, speculating that dental crowding may result from continued interbreeding between physically dissimilar ethnic groups. However, Lombardi[75] stated that the low incidence of crowding in primitive populations seemingly results from the high degree of interproximal attrition and not from a more harmonious balance of tooth and jaw size. It has been shown that variability is an important component in the make-up of the human dental structure. Tooth morphology is under rigid genetic control and the genes that determine whether or not the morphologic traits will be expressed are independent of each other.[76-82]

The size of teeth has been demonstrated to be dependent upon race and sex.[78,83] Marked racial differences exist in the size of teeth, with the Lapps probably having the smallest teeth and the Australian aborigines the largest.[84] Tooth size was found to be significantly larger in Negroids than in Caucasoids or Mongoloids.[85] Tooth size also differs according to sex, in that the teeth of males are an average four percent greater in mesiodistal length than females.[86] This sexual dimorphism varies from tooth to tooth, being greatest in the canines.[87] Investigators have demonstrated this difference regardless of race.[83,88] Therefore, in a study of tooth sizes, males and females should be reviewed separately whenever possible, and race should be controlled in sample selection for the study of tooth size.[76]

The environmental factors that are speculated to affect crowding in today's industrialized population include a refined diet which can cause loss of arch length through dental caries. A reduction in muscle stimulation required for mastication of softer foods causes a decrease in the expression of facial bone growth and less interproximal tooth attrition.[74,89] Dental crowding may also result from aberrant eruptive paths, abnormal muscle forces, and occlusal forces resulting in improper migration of the teeth.

Many investigators have suggested directly or by implication that dental crowding is usually associated with the presence of large teeth.[90-99] However, investigators studying the interrelationship of tooth size, arch size, and dental crowding have reported dissimilar findings. Two groups of investigators emerge. The first group found that tooth size correlated with crowding.[76,96,99,100] A second group reported quite different findings. Mills[101] and McKeown[102] found greater correlation between arch size and dental crowding than between tooth size and dental crowding. Howe et al.[103] found, statistically, that crowded and noncrowded groups could not be distinguished from each other on the basis of mesiodistal tooth diameters; rather, the crowded group was found to have smaller dental arch dimensions than the noncrowded group. While differences in the sample and the methods of the various studies could partially account for dissimilar findings, an adequate explanation for the disparate results was not found.[103]

THE SHAPE OF THE DENTAL ARCH

Many orthodontic concepts of the human dental apparatus are based on studies of two-dimensional cephalograms. However, the development of three-dimensional concepts of these complicated mechanisms is needed for a more complete understanding.[104] The size and shape of the dental arches have been studied for over a century.[105-107] The shape of the dental arches has been described as semi-ellipsoid by Black,[107] and paraboloid by Angle.[108] Williams[109] described the position of the six maxillary anterior teeth as lying on the arc of a circle with its center midway between the buccal groove of the first molars. Hellman[110] investigated the skulls of humans and apes and found no relation between the size of teeth and the form of the dental arches. He did not accept the theories of arch predetermination based on measurements of certain teeth. Stanton[111] advocated a mathematical approach for the study of malocclusions utilizing solid geometry and various engineering principles. Lasher[112] constructed a series of geometric charts for comparison with dental arches; these comparisons showed the anterior teeth located along a semicircle with line diverging backward from the canines through the premolars and molars to accomodate the buccal teeth. MacConaill and Scher[113] compared catenary curve forms with the "common line of occlusion" derived by connecting loci on the teeth of both arches. Further, they pointed out that "the catenary," like a straight line, is a curve of minimal extraneous force and, therefore, is the simplest form in which the teeth can be arranged. Another curve would require definite extraneous forces to distort the arcade from the catenary form. They stated that gross departures from one or another of a certain group of "ideal" shapes of the dental arcade are due to pathological causes. Scott[114] supported the concept of the "catenary form" in that the teeth are tied together by transseptal fibers like the links in a chain. He observed that the dentition maintains the primordial catenary form because the human alveolar growth process does not show regional differentiation but remains more or less equal in amount and constant in direction in all parts of the arch. Sved[115] proposed the hypothesis of spherical occlusion; that is, the function of mastication tends to take place on the surface of a sphere. He contended that the anterior teeth are arranged along a curve resembling a circle, with the posterior teeth on nearly straight lines.

More recently, the computer has been used to mathematically reproduce the curvature of the dental arches.[116-119] Lu[118] employed polynomials to represent dental arches and provided a means of analyzing dental arch symmetry by substituting various arch measurements into a polynomial equation of the fourth degree. Sampson[105,120] provided a statistical analysis using conic sections to represent the shape of the maxillary arch. In summary, this review emphasizes the widely divergent views concerning arch form, shape and methods of evaluation.[116] The determination of the arch form in orthodontic practice remains an empirical art rather than an exact science.

The effect of heredity on arch form has been established from family,[121] twin,[122] and population studies.[123] The size and shape of the dental arches are subject to considerable variation, being dependent upon the form and position of the tooth crowns.[124] The position of the clinical crowns is, in turn, affected by tooth eruption[125] and migration,[126] the size of adjacent teeth,[127] and jaw growth.[128]

Other factors affecting the form of the dental arch include the degree of equilibrium between the surrounding orofacial musculature.[129] Brader's[130] study of dental arch form related to intraoral forces supported the following conclusions:

1. Dental arch form consists of the teeth arranged in unique positions along a compound curve, which represents a steady state of equilibrium limited by counterbalancing force fields of the tongue and of the circumoral tissues.
2. The cirvilinear geometry of dental arch form can be ascertained by describing the commonality of the collective positions of all the teeth present.
3. The unique geometry of the curve representing dental arch form is approximated by a closed curve with trifocal properties, with the teeth occupying only a portion of the total curve at its constricted end.
4. The primary determinants of arch form morphology are the muscle and tissue forces of the resting state in contradistinction to the intermittent forces of muscles in functioning states.
5. The geometry of the curve of dental arch form is related with the resting forces of the tongue so that PR=C, where: P = Pressure/unit area; R = A radius of curvature at a point along the compound curve corresponding precisely with the pressure site; and C = "A mathematic constant," exhibiting variation in magnitude between individuals, and variation in the same individual at different physiologic ages.
6. Considering the circumoral structures as an elastic envelope, the lips and cheeks exert counter-balancing inward tensions against the teeth according to the following equation describing forces across the surface of any elastic container:

$Pi = Pe + T\ (1/R + 1/R')$ where: Pi = internal forces; Pe = external forces; T = tension of the elastic envelope; R = radius of curvature in the horizontal plane; R' = radius of curvature in the transverse plane.

7. At least two separate constraints modulate the horizontal form of the dental arch: the mathematic constant of the tongue muscle energy (C of No. 5 above), and the elastic tension of the lips and cheeks (T of No. 6 above).
8. Arch form characteristics are such that the form is stabilized, and dental equilibrium is attained wherever the mathematic constant of tongue muscle energy (C) equals the elastic tension of the lips and cheeks (T). Transitional or temporary variations in the relationship between C and T can alter arch form during growth or pathologic conditions.

The shape of the dental arch has been described in various ways. The curves utilized are called conic sections, because they can be formed by the intersection of a plane with a right circular cone. If the plane is perpendicular to the axis of the cone, the intersection will be a circle. If the plane is slightly tilted, the result will be an ellipse. If the plane is parallel to one element of the cone, the result is a parabola (Figure 2).

The general equation for the simple parabola is: $Y = X^2/4P$ where the (0,0) is the vertex of the parabola, and (0,P) is the focus. The line containing the focus and the vertex is referred to as the axis of the parabola. The median raphe of the palate is the axis of the parabola for the maxillary arch. The mandibular lingual frenum establishes the vertex for the lower arch; however, it is not as reliable a reference as the median raphe.[131]

The equation for the catenary curve can be transformed into the following: $R = (s^2 - h^2)/2h$ where "s" is half the width of the curve and "h" is the vertical distance from the apex of the catenary curve to the horizontal line joining the points of "suspension," which are the reference points of the molars. "R" is the radius of the curvature of the catenary at its apex, and is a quantity which defines any catenary uniquely.

The general question for the simple ellipse is given as: $x^2/a^2 + y^2/b^2 = 1$ when the ellipse is centered at the point (0,0).

The morphologic differences in dental arch shape proposed by various investigators are in part related to the selection of coordinate points on the occlusal zone of the dentition. Currier[104] determined that the ellipse is a better geometric figure than the parabola for describing the form of both the maxillary and mandibular arches when landmarks on the facial surfaces of the teeth are used for comparison. However, the parabola did show a significantly better fit than the ellipse when the curve of the mandibular arch passed through the central fossae of molars, occlusal fissures on premolars, and cinguli on canines and incisors. The reference points used to establish the arch curvature should represent the true tooth position and be independent of the number of cusps, location of cusps, abrasion or eruption level; for the purpose of recording the space relationships within the dental arch the contact points must be used.[132] Sampson[105,120] provides a statistical analysis of arch shape with conic sections with the centroids of the first molars as the end points and passing as near as possible to the other teeth. Because of the statistical nature of the "model arc," it can be used as an "average" or "most likely shape" with which to compare idividual arches as to their shape and symmetry.

The concept of the "line of occlusion" unites the variables of tooth size, arch length, and arch shape. The line of occlusion, in other words, is the position which the teeth must occupy to be in stability and harmony with each other and with all other anatomic structures.[133] In treatment, an accurate evaluation of arch length discrepancy is related to correct arch form, and correct arch form is important for denture stability.[134]

The shape of the dental arch also has implications for treatment planning cleft lip and palate repair and understanding the natural history of the palatal cleft defect and the face in which it exists.[135] Howe et al.[103] noted on visual inspection that noncrowded arches were easily identifiable, with broad symmetrical forms; in contrast, the crowded arches were sometimes asymmetrical, frequently narrow or tapered, and irregular in arch form. Sampson and Richards[136] noted that individuals whose incisor crowding was static or decreased tended to have dental arches which were initially narrower, shallower, and more crowded. Staley et al.[137] concluded that the maxillary dental arch, as a whole, is narrower in adults with Class II, Division 1 malocclusion than it is in adults with normal occlusion. The shape of the dental arch is therefore of primary concern to the dentist managing developing occlusions, especially as it relates to the ability to predict future growth changes and treatment results.

METHODS AND MATERIALS

This study investigated the development of a microcomputer program to assist in the diagnosis of space analysis in the mixed dentition. A modification of the "prototype program" was then developed for clinical studies of dental crowding. This customized modification program was utilized to analyze dental crowding and its relationship to tooth size, arch dimension, and arch form in the mixed dentition.

The Apple (Apple II, II+, IIe and IIc and Applesoft are trademarks of the Apple Computer Corporation, 20525 Mariani Avenue, Cupertino, California, 95014) was chosen because of its widespread use, the variety of available software, and the relationship of cost to performance.[2] The computer system utilized is typical of most home or personal systems. The type of computer equipment necessary for analysis includes (Figure 1):

1. The Apple II personal computer with keyboard and 80 column expansion card.
2. A video display terminal (VDT).
3. A 5.25 inch Apple Disk II Drive. (A means of "running" a stored program.)
4. Floppy diskette, 5.25 inch, double density single or double sided.
5. A printer which produces a "hard copy" of the determined values.

The program is written in "Applesoft" BASIC and is compatible for use with the Apple II series of personal computers. As each make of personal computer utilizes a slightly different version of BASIC, the program listing must be modified to run on other brands of personal computers. However, only minor changes in the program would be required for use on another microcomputer.[2] The "Mixed Dentition Arch Length Analysis Adapted for the Apple IIe Personal Computer," is an analysis program similar to that advocated by Moyers,[56] and is written to be "user-friendly," in that it directs the clinician through the analysis from start to finish.

When activated or "RUN," the program begins with an introductory statement of user liability and a "main options" menu, which allows the clinician to (1) choose to perform the analysis, (2) go to a discussion of space analysis, (3) view patient computer-assisted instruction on space analysis, or (4) exit the program and return to Applesoft Basic (40 column display). The analysis begins by asking for demographic information about the patient: name, age, identification number, and date of the analysis. The clinician is then directed to enter the measurements of tooth size and alveolar bone length in millimeters. After the clinician has supplied the initial measurements, the computer completes the mathematical calculations. The amount of space available for ideal alignment of the dental arch is determined by comparing alveolar bone length to the total tooth mass which must occupy the space. The program uses an internal probability table to determine the size of the unerupted permanent canines and premolars. The values are at the 75 percent level of probability.[56] This level of probability has been found to be most useful from the clinical standpoint.[50] The program also automatically takes into account arch length decreases due to the mesial migration of the first permanent molars during the replacement of the primary molars and eliminating the "leeway space."

The program displays the results of the space analysis on the computer's video display screen. Each dental segment is presented, as well as an overall arch analysis. The calculations determine if a redundancy or inadequacy exists. A positive number indicates an arch length redundancy, and a negative number indicates an inadequacy. If the computer system is equipped with a printer, the dentist can obtain a printout of the results of the analysis. The printout then can become a part of the patient's record, and/or a copy can be given to the parents as part of the treatment plan presentation (Figure 3). A short discussion of interceptive orthodontic treatment considerations is included in the program as a sub-routine program for the practitioner. Also, a patient instructional tutorial sub-routine program provides a further aid during treatment plan presentation.

Eighty articulated plaster study models of children in the mixed dentition were examined utilizing the computer analysis and a traditional paper and pencil analysis. The study models were obtained from the Dental Clinic of the James Whitcomb Riley Hospital for Children, and the Undergraduate Clinic, Department of Pediatric Dentistry at the Indiana University School of Dentistry. Measurements of the dentition and the alveolar bone segment lengths were made with sliding calipers with a vernier scale. The eruption of the mandibular permanent incisors was necessary before the analysis could be undertaken. Prior to their clinical emergence, sufficiently accurate measurement of their mesiodistal widths would have been impossible, thus undermining the accuracy of the space analysis.[8] The program's reliability was determined by statistical verification of the data results between traditional paper and pencil computations of space analysis (Texas Instruments TI-30 SLR Hand Calculator, Texas Instruments Corporation, Lubbock, Texas, 79406) and the computer results. The mean, standard deviation, and student's t distribution were utilized in the statistical anaylsis. The Pearson product-moment correlation coefficient, or Pearson r, was used to show the statistical relationship between computer results and hand calculations.[138]

To examine the extent to which tooth size and jaw size contribute to dental crowding in the mixed dentition, a "customized modification" of the "prototype program" was utilized. A sample of 80 subjects' articulated study models from the Dental Clinic of the James Whitcomb Riley Hospital for Children, and the Undergraduate Clinic, Pediatric Dentistry Department at the Indiana University School of Dentistry were selected. The sample population represented 60 white children, 28 male and 32 female; and 20 black children, 7 male and 13 female. The mean age of the population was 115.56 months, with a range of 64 to 163 months.

Measurements made from dental casts are more consistent and, therefore, more accurate than direct measurements taken from the mouth particularly in the posterior segments.[76] Each dental model selected met the following criteria:

1. The casts represented the mixed dentition, with eruption of all permanent first molars and all mandibular and maxillary permanent incisors.

2. There was no previous orthodontic treatment.
3. There was no premature loss of space due to dental caries or extractions.

The sample was divided into two groups based on the amount of dental crowding in either arch, as determined from the computer analysis. Values for total arch tooth mass were obtained through the computer analysis which uses Moyers' prediction table at the 75 percent level of probability. Models with up to 4 mm of crowding were placed in Group I (noncrowded arches), and Group II included casts with more than 4 mm of dental crowding (crowded arches). This division was based on clinical considerations, since many clinicians regard a dental arch to be crowded if it has a space inadequacy of more than 4 mm.[76] Means and standard deviations of the following arch parameters were used to compare the two groups.[138] Tooth size measurements used for comparison included total incisor tooth mass and individual tooth size of the central and lateral incisor. Variables for arch dimensions included arch perimeter, arch depth, arch width, and arch symmetry. Arch shape was numerically defined by the eccentricity value of an ellipse. The eccentricity of the ellipse expresses the degree of "nonroundness" or "flatness" of an ellipse. The ratio of total incisor tooth mass to arch width and the ratio of arch width to arch perimeter were also compared between Group I and II for each arch.

The "modification" program used the following methods for its analysis of study models in the mixed dentition and provided a printout of all data entries and calculations (Figure 5). Space analysis measurements were made manually with sliding calipers with a vernier scale calibrated to 0.1 mm. Measurements were taken from maxillary and mandibular pretreatment plaster casts poured from alginate impressions. Measurements of tooth size were taken at the greatest mesiodistal width of each tooth, with the caliper tips held perpendicular to the long axis of each tooth.[76] Arch perimeter measurements were obtained from the casts measuring the alveolar length for each dental sextant, in a manner advocated by Moyers.[56]

The following clinical measurements in millimeters were obtained from each model:

1. Mesiodistal width of tooth #23.
2. Mesiodistal width of tooth #24.
3. Mesiodistal width of tooth #25.
4. Mesiodistal width of tooth #26.
5. Left posterior alveolar segment (K-M).
6. Left anterior alveolar segment (23-24).
7. Right anterior alveolar segment (25-26).
8. Right posterior alveolar segment (R-T).
9. Mesiodistal width of tooth #7.
10. Mesiodistal width of tooth #8.
11. Mesiodistal width of tooth #9
12. Mesiodistal width of tooth #10.
13. Right posterior alveolar segment (A-C).
14. Right anterior alveolar segment (7-8).
15. Left anterior alveolar segment (9-10).
16. Left posterior alveolar segment (H-J).

17. Maxillary arch depth.

18. Maxillary right arch width from midline.

19. Maxillary left arch width from midline.

20. Mandibular arch depth.

21. Mandibular right arch width from projected maxillary midline.

22. Mandibular left arch width from projected maxillary midline.

Dental crowding or noncrowding was calculated without consideration of a future loss of "leeway space." The program did not subtract for mesial migration of the permanent first molars prior to its occurring. Comparisons of tooth sizes for central and lateral incisors were made by averaging left and right sides. Ballard's[139] study noted asymmetry in tooth size, with 90 percent of teeth demonstrating a right-left discrepancy in mesiodistal width amounting to 0.25 mm or more. The program calculated arch perimeter and arch width from the summation of data measurements. The ratio of total incisor tooth mass to arch width and the ratio of arch width to arch perimeter were mathematically determined.

Computation of arch shape was made using the eccentricity value of an ellipse to numerically describe arch form. The purpose of this investigation was not to define an equation for dental arch shape, but to compare the variability in dental arch shape between crowded and noncrowded individuals. The standard curve of an ellipse was utilized to describe the dental arch (Figures 6 and 7).

The equation of an ellipse with its center located at the origin (0,0), a semimajor axis of length "a," and a semiminor axis of length "b" is: $x^2/a^2 + y^2/b^2 = 1$.

The dental arch semimajor axis was defined as the median palatal raphe for the maxillary arch. The semimajor axis of the mandibular arch was a projection of the maxillary median palatal raphe to the mandibular arch with the study models fully articulated.[140] The median palatal raphe has been found to be a more reliable reference axis than mandibular lingual frenum attachment.[131]

Arch depth or the length of semimajor axis "a," was defined as the distance from the contact point or incisal edges of the central incisors to the minor axis. The minor axis or arch width was defined as the line connecting the contact points on the mesial of the first permanent molar for the maxillary and mandibular arches.

The semiminor axis "b" was one-half the total arch width. The semiminor axis "b" for the maxilla was the distance from the median raphe to the contact points on the mesial of the first molar. The semiminor axis for the mandibular arch was the distance from the projected median palatal raphe to the contact points on the mesial of the first mandibular molar.[140]

Although all parabolas have the same basic shape and differ only in the scale to which they are drawn, the same is not true of ellipses.[141] This variation in shape is defined as the "eccentricity of the ellipse." It is expressed numerically as: $e = ((a^2 - b^2)^{(\frac{1}{2})}) /a$. The value "e" is a number between 0 and 1 that measures the shape of the ellipse. An ellipse with an eccentricity of 0 is the same as a circle. An ellipse with a higher eccentricity has a flatter shape.[141,142] The eccentricity of an ellipse actually describes the shape of the arch compared to other methods[143] which express a numerical ratio between arch width and depth (Figure 8).

As the values of semiminor axis "b" may vary from the right and left sides of the dental arch, the eccentricity value can also be used to evaluate the symmetry of the arch. For example, if a dental arch is perfectly symmetrical, the semiminor axis "b" will be the same value for the right and left sides of the arch, or b (right side) = b' (left side). Therefore, in the symmetrical arch: e (right side) = e' (left side). This could then be expressed as: $e/e' = 1$ where the value 1 would express perfect symmetry. Kurt et al.[144] used a similar ratio relationship to express lateral cross bite and sagittal cross bites in cleft palate cast analysis. The program calculated the eccentricity of the arch, as defined by an ellipse, for both right and left halves, and gave an average value for the arch. The symmetry of the dental arch was calculated as the ratio of eccentricity values of right to left halves.

Moyers' Analysis prediction table values were established from the Center of Human Growth and Development of the University of Michigan study sample.[145] To compare the sample population of this study with that of the Michigan sample, various arch measurements were compared statistically. The values utilized for the comparison were an average of the nine and 10 year values for both males and female subjects of the Michigan sample. The two groups' means, standard deviation, as well as the statistics, were compared.[138]

All measurements were made by one investigator. Double determinations were made for 10 subjects, 22 measurements per case, several months after the initial recordings, and the difference between measurements was compared by the t test for paired samples. In addition, the standard deviation of a single measure was calculated to determine the extent to which the variability caused by measurement error affected the observed variance. Statistical analysis for systemic error and estimating random errors using these values were undertaken.[146]

RESULTS

The prototype program, "Moyers' analysis of the mixed dentition," was found to be accurate in its calculation of space adequacy or inadequacy. When the results of the computer program analysis were compared to those of a hand calculator, there was no statistical significant difference between computer results and manual calculations ($t = 0$). The coefficient of correlation between the two methods' calculated results was one ($r = 1$). A typical time for the process of entering the data into the computer, calculations, and printout was under five minutes, per individual study model (Table I).

The "modification" program developed for analysis of dental crowding and its relationship to dental arch variables was found to be accurate in its performance of all data calculations. There was no significant difference between computer and manual calculations ($t = 0$). The analysis of dental crowding and its relationship to tooth size and arch dimensions yielded significant results for both dental arches. Significant differences were found in total incisor tooth mass between the noncrowded and crowded groups. Crowded groups had larger teeth. Significant differences were also noted in arch perimeter and arch depth: both were significantly smaller in the crowded group. Significant differences were likewise demonstrated in the shape of dental arches for crowded and noncrowded groups.

A total of 80 articulated study models were examined (Table II). The total sample was divided into two groups based on the amount of dental crowding in the arch. Analysis of the data was undertaken for total crowded and noncrowded group values. There were 54 maxillary and 69 mandibular models in Group I, noncrowded cases. The mean space analysis for the maxillary noncrowded cases was 0.92 mm excess. The mandibular arch had 1.61 mm excess. The sample of crowded individuals, Group II, consisted of 26 maxillary arch cases and 11 cases for the mandibular arch. The mean space analysis for crowded maxillary arches showed a -6.52 mm deficiency. For crowded mandibular arches there was -7.34 mm deficiency.

Analysis of total tooth mass of the incisors between the noncrowded and crowded groups yielded statistical differences ($p < 0.05$). Crowded individuals had larger total incisor tooth mass than noncrowded individuals. The difference in the mean values of maxillary total incisor mass between crowded and noncrowded groups was 0.78 mm. The difference between the mean values for the corresponding comparison in the mandibular arch was 1.8 mm. Comparisons of individual tooth size differences between the crowded and the noncrowded groups were of varied significance ($p < 0.05$). The difference of 0.14 mm in the mean values of the maxillary central incisors between crowded and noncrowded groups was not significant. However, the central incisors of the mandibular arch showed a difference of 0.39 mm in mean values between the two groups, which was significant ($p < 0.01$). Both arches demonstrated significant differences in individual tooth size between groups with respect to the lateral incisors ($p < 0.01$) (Tables III-V).

Arch dimension comparisons yielded significant differences between the crowded and noncrowded groups. Crowded arches tended to be smaller than noncrowded arches. The average maxillary dental arch perimeter for the noncrowded group was 77.36 mm, which was significantly larger than the average value of 71.49 mm for the crowded group ($p < 0.01$). Similar findings were observed for the mandibular arch perimeter. The average mandibular dental arch perimeter for the noncrowded group was 68.87 mm, significantly larger ($p < 0.01$) than the average value of 63.99 mm for the crowded group. Arch depth is statistically greater ($p < 0.01$) in noncrowded individuals than in crowded individuals. The maxillary arch depth averaged 30.45 mm in the noncrowded group, 3.03 mm larger than the crowded group's mean measurement. The corresponding mandibular arch measurement averaged 24.64 mm in the noncrowded group, 2.01 mm larger than the crowded group. No significant difference ($p < 0.05$) was observed for arch width or arch symmetry in crowded and noncrowded groups for either dental arch. Noncrowded arches, therefore, are not more symmetrical than crowded arches. This is not to be confused with dental irregularity of tooth positions, which was not examined in this study. The eccentricity value, or overall shape of the dental arch, was significantly different between the two groups ($p < 0.01$). The eccentricity value for the maxillary noncrowded arch was 0.72, as compared to the crowded arch value of 0.64. The corresponding mandibular values were 0.61 for the noncrowded arches and 0.54 for crowded arches. An ellipse with a higher eccentricity has a flatter shape; the noncrowded arches are, therefore, flatter than crowded arches.

Indices of crowding, defined as ratios of arch dimensions, yielded significant differences between noncrowded and crowded groups.

The ratio of incisor total tooth mass to arch width (T/W) was significantly different between groups for both arches ($p < 0.01$), being larger in crowded individuals, and thus reflecting the larger tooth size found in this group. The ratio of arch width to arch perimeter (W/P) was also significant ($p < 0.05$) between the two groups for both arches. The ratio was larger in crowded individuals, reflecting the small arch perimeter found in the crowded group. The arch width was not significantly different in either arch for either group. Overall, crowded dental arches were significantly different from noncrowded arches in having both larger tooth size and smaller arch perimeter.

The arch characteristics of this study's sample population were compared to those of the sample at the Center of Human Growth and Development of the University of Michigan sample.[145] For the majority of values compared there were no significant differences ($p < 0.01$). Significant differences ($p < 0.01$) were noted, however, in the width and depth of the mandible, the Indiana sample being significantly smaller. However, the overall mandibular arch perimeter was not significantly different. The sample population of this study overall was similar to the Michigan sample from which Moyers' Analysis prediction table was established (Table VI).[56]

The experimenter's error of measurement was not significant ($p < 0.10$) for 19 of the individual measurements made on a model analysis. A significant difference ($p < 0.10$) was noted in the individual measurements of the mandibular anterior alveolar sextant. The error in mandibular anterior alveolar segment determination was related to the crowding found in this sextant and the placement of reference determination when there was overlap of the permanent lateral incisor and primary canine. However, there was no significant difference for overall mandibular perimeter. Therefore, there were no significant differences of measurements utilized for arch analysis determinations of crowded and noncrowded cases (Tables VII-X).

FIGURES AND TABLES

Figure 1. A typical microcomputer system.

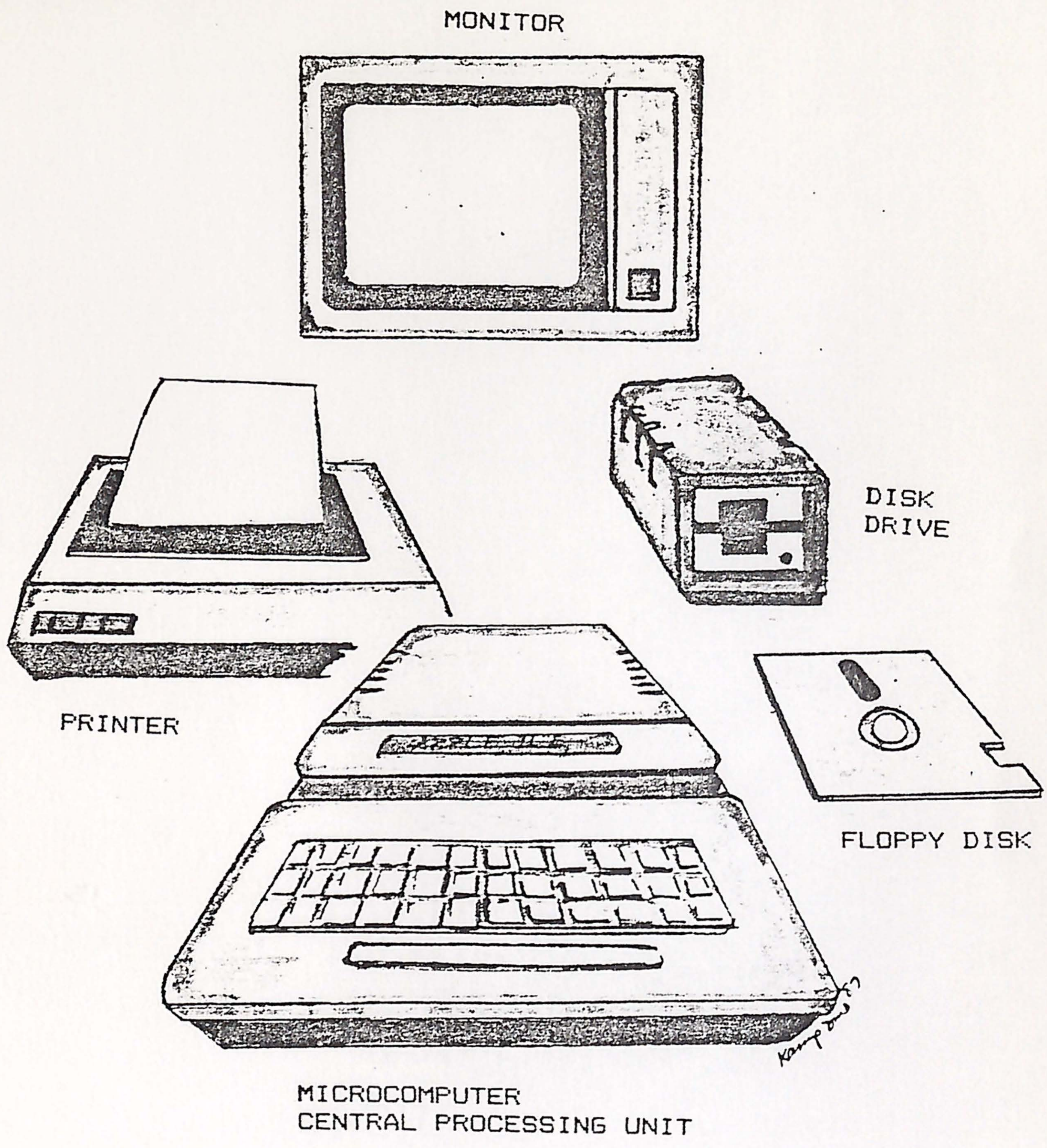
MONITOR
DISK DRIVE
PRINTER
FLOPPY DISK
MICROCOMPUTER
CENTRAL PROCESSING UNIT

Figure 2. The curves utilized to describe dental arch form are called conic sections, because they can be formed by the intersection of a plane with a right circular cone.

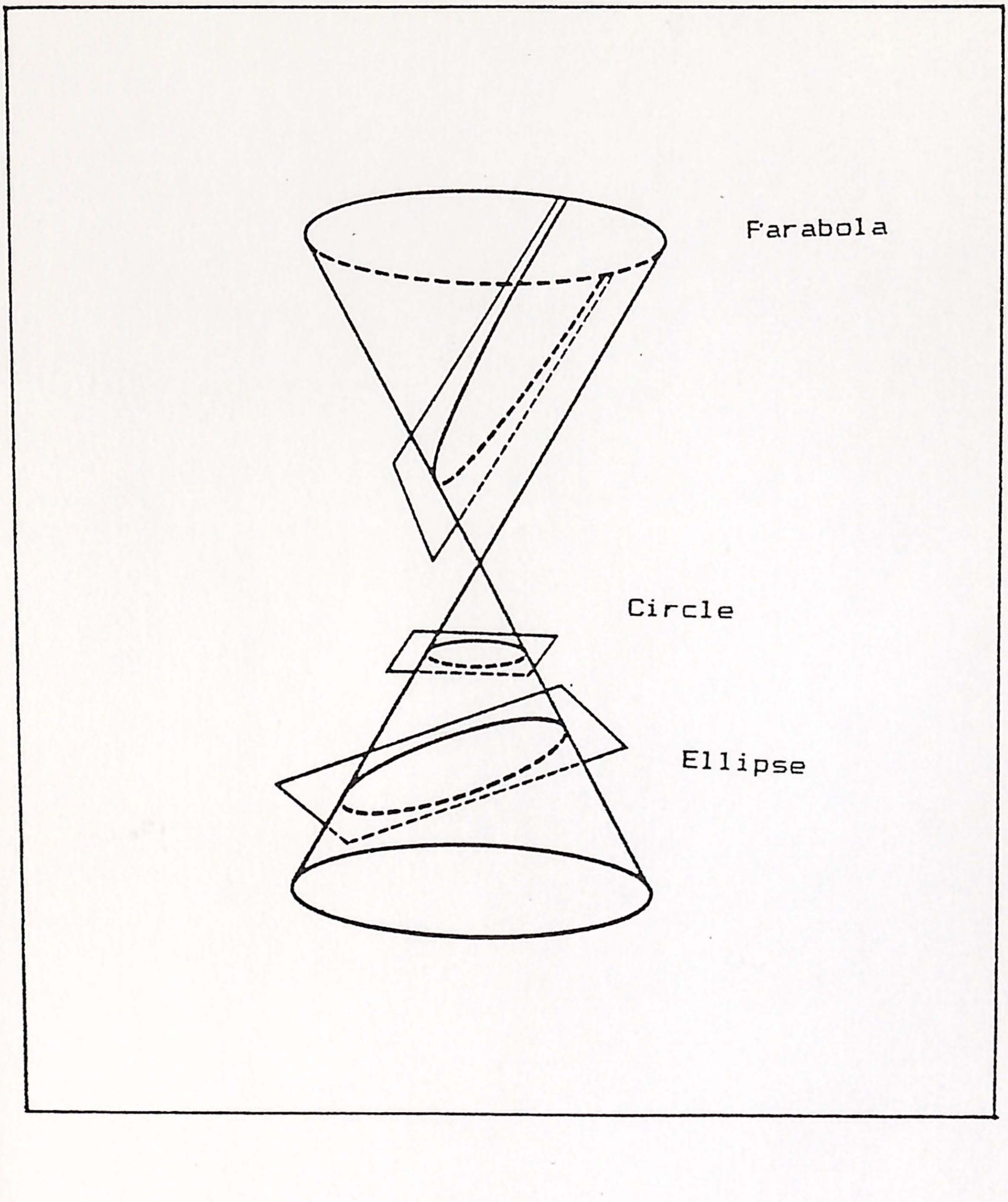
Parabola
Circle
Ellipse

Figure 3. Schematic of overall program flow for "Mixed Dentition Arch Length Analysis Adapted for the Apple IIe Personal Computer."

Introductory programs:

HELLO PROGRAM "Loads DOS & programs"
GRAPHICS II PROGRAM "High resolution graphic"
INTRODUCTION MIXED DENTITION ANALYSIS "Text"

Main Programs:

MIXED DENTITON ANALYSIS

Disclaimer of Liability

Main Menu

1. Moyers' Analysis
2. Discussion of Analysis and Clinical Application
3. Computer Graphics for Patient Education
4. Exit to "Applesoft"

Data value input

Data calculations

Display of analysis results to video monitor

Sub-menu

1. Repeat display to monitor
2. Printout of analysis
3. Return to main menu

Figure 4. Printout of the results of the analysis. The printout can become a part of the patient's record, or a copy can be given to the parents as part of the treatment plan presentation.

```
                         MIXED DENTITION ANALYSIS
                      FOR ARCH LENGTH DETERMINATION

--------------------------------------------------------------------------------

NAME:  JOHN DOE

AGE: 9 YEARS 5 MONTHS                        IDENTIFICASTION #: 12345678
SEX: MALE                         DATE OF ANALYSIS: 31 MAY 1987

============================= RESULTS OF ANALYSIS =========================

Overall the Maxillary Arch has 11 millimeters of space ADEQUACY
Overall the Mandibular Arch has 1.2 millimeters of space ADEQUACY
============================= SEGMENT ANALYSIS ==========================
Overall the Maxillary Incisal Segment has 2 millimeters of space ADEQUACY
     ALVEOLAR BONE LENGTH: 32
     TOTAL TOOTH MASS: 30
--------------------------------------------------------------------------------
The Maxillary Right Posterior Segment has 4.5 millimeters of space ADEQUACY
     ALVEOLAR BONE LENGTH: 28
     TOTAL TOOTH MASS: 22.6
[ MOLAR SHIFT OF -0.9mm WAS UTILIZED ]

--------------------------------------------------------------------------------
The Maxillary Left Posterior Segment has 4.5 millimeters of space ADEQUACY
     ALVEOLAR BONE LENGTH: 28
     TOTAL TOOTH MASS: 22.6
[ MOLAR SHIFT OF -0.9mm WAS UTILIZED ]

===============================================================================
The Mandibular Incisor Segment has 1 millimeters of space ADEQUACY
     ALVEOLAR BONE LENGTH: 24
     TOTAL TOOTH MASS: 23
--------------------------------------------------------------------------------
The Mandibular Right Posterior Segment has .1 millimeters of space ADEQUACY
     ALVEOLAR BONE LENGTH: 24
     TOTAL TOOTH MASS: 22.2
[ MOLAR SHIFT OF -1.7mm WAS UTILIZED ]

--------------------------------------------------------------------------------
The Mandibular Left Posterior Segment has .1 millimeters of space ADEQUACY
     ALVEOLAR BONE LENGTH: 24
     TOTAL TOOTH MASS: 22.2
[ MOLAR SHIFT OF -1.7mm WAS UTILIZED ]

================== ADJUSTMENTS IN ASSESSMENT OF SPACE ANALYSIS =============

     Anteriorposterior position of the incisors:______________
     Adjustment for correction of Curve of Spee:______________
     Arch expansion:__________________________________________
     Space availability following tooth extraction:___________
     TOTAL ADJUSTMENTS TO ARCH LENGTH:________________________
============================= REMARKS / NOTES ==============================
```

Figure 5. Printout of the customized modification program to examine the extent to which tooth size and jaw size contribute to dental crowding in the mixed dentition.

```
        COMPUTERIZED EXAMINATION OF DENTAL CROWDING AND ITS
        RELATIONSHIP TO TOOTH SIZE,ARCH DIMENSION, AND FORM
*****************************************************************

********************** DEMOGRAPHIC INFORMATION ******************

     NAME:  JOHN DOE
     AGE:  5 YEARS [illegible] MONTHS
     SEX:  OTHER

********************** DATA INPUT VALUES ***********************

--------------------- SPACE ANALYSIS/TOOTH SIZE -----------------

     [ MANDIBULAR ARCH ]

     TOOTH (#23):  6
     TOOTH (#24):  5.5
     TOOTH (#25):  5.5
     TOOTH (#26):  6

     RIGHT POSTERIOR BONE LENGTH:  22
     INCISOR BONE LENGTH:          21
     LEFT POSTERIOR BONE LENGTH:   21

     [ MAXILLARY ARCH ]

     TOOTH (#7):  7
     TOOTH (#8):  8
     TOOTH (#9):  8
     TOOTH (#10): 7

     RIGHT POSTERIOR BONE LENGTH:  24
     INCISOR BONE LENGTH:          30
     LEFT POSTERIOR BONE LENGTH:   24

------------------------- ARCH FORM DATA ------------------------

     MAX ARCH DEPTH (A):  27
     MAX RIGHT WIDTH (B): 19
     MAX LEFT WIDTH (B'): 20

     MAND ARCH DEPTH (A): 22
     MAND RIGHT WIDTH (B): 16.5
     MAND LEFT WIDTH (B'): 17

*********************** DATA CALCULATIONS ***********************

     [ OVERALL ARCH SPACE ANALYSIS ]

OVERALL THE MAXILLARY ARCH HAS 2.8 MILLIMETERS OF SPACE ADEQUACY
OVERALL THE MANDIBULAR ARCH HAS -2.4 MILLIMETERS OF SPACE INADEQUACY

     [ SEGMENT ANALYSIS ]
OVERALL THE MAXILLARY INCISAL SEGMENT HAS 0 MILLIMETERS OF SPACE ADEQUACY

THE MAXILLARY RIGHT POSTERIOR SEGMENT HAS 1.4 MILLIMETERS OF SPACE ADEQUACY
THE MAXILLARY LEFT POSTERIOR SEGMENT HAS 1.4 MILLIMETERS OF SPACE ADEQUACY

THE MANDIBULAR INCISOR SEGMENT HAS -2 MILLIMETERS OF SPACE INADEQUACY
THE MANDIBULAR RIGHT POSTERIOR SEGMENT HAS -.2 MILLIMETERS OF SPACE INADEQUACY
THE MANDIBULAR LEFT POSTERIOR SEGMENT HAS -.2 MILLIMETERS OF SPACE INADEQUACY

-------------------- ECCENTRICITY OF THE ARCH -------------------

ECCENTRICITY MAX RIGHT: .71
ECCENTRICITY MAX LEFT:  .67

ECCENTRICITY AVE MAX: .69

ECCENTRICITY MAND RIGHT: .61
ECCENTRICITY MAND LEFT: .63

ECCENTRICITY AVE MAND: .62

------------------------ ARCH SYMMETRY -------------------------

MAXILLARY ARCH (R/L): 1.06
MANDIBULAR ARCH (R/L): 1.03

--------------- MILLS + HAMILTON ARCH LENGTH -------------------

MAX ARCH (RIGHT ONLY): 73.02
MAND ARCH (RIGHT ONLY): 61.58

DIFFERENCE(ACTUAL-CALC)MAX:4.98
DIFFERENCE(ACTUAL-CALC)MAND: 2.42

ACTUAL MAX ALVEOLAR LENGTH: 78
ACTUAL MAND ALVEOLAR LENGTH: 64

*****************************************************************
---------------------------- PONT ANALYSIS ----------------------

PONT VALUE MAX ARCH: 37.5
ACTUAL MAX ARCH WIDTH: 39
DIFFERENCE (ACTUAL - PONTS):  1.5

PONT ANALYSIS MAND ARCH VALUE: 28.75
ACTUAL MAND ARCH WIDTH: 33.5
DIFFERENCE (ACTUAL-PONTS): 4.75

------------------------ TOOTH MASS AVERAGES --------------------

MAND INCISOR TOOTH MASS: 23
AVG MAND CENTRAL INCISORS: 5.5
AVG MAND LATERAL INCISORS: 6

AVG MAX INCISOR TOOTH MASS: 30

AVG MAX CENTRAL INCISORS: 8
AVG MAX LATERAL INCISORS: 7

---------------BOLTON INTERARCH TOOTH RATIO TYPE ANALYSIS-------------
ANTERIOR RATIO (MAND MASS / MAX MASS): [illegible]
-----------------------RATIO (TOTAL INCISORS/WIDTH)----------------

MAX RATIO (TOTAL INCISORS/WIDTH):  .77

MAND RATIO (TOTAL INCISORS/WIDTH):  .69

---------------------RATIO (WIDTH/ARCH LENGTH)--------------------

MAX RATIO(WIDTH/LENGTH):  .5

MAND RATIO(WIDTH/LENGTH):  .52

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```
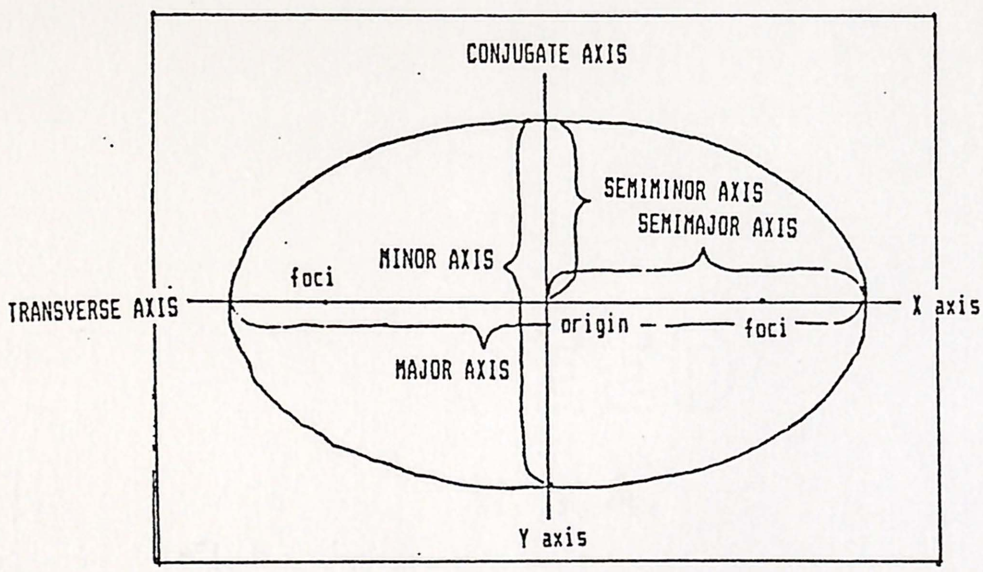

Figure 6. A closed elliptic curve which serves as a geometric model of arch form.



CONJUGATE AXIS
SEMIMINOR AXIS
SEMIMAJOR AXIS
MINOR AXIS
foci
TRANSVERSE AXIS
X axis
origin
foci
MAJOR AXIS
Y axis

Figure 7. Superimposed elliptic curve over occlusal view of dental arch form.

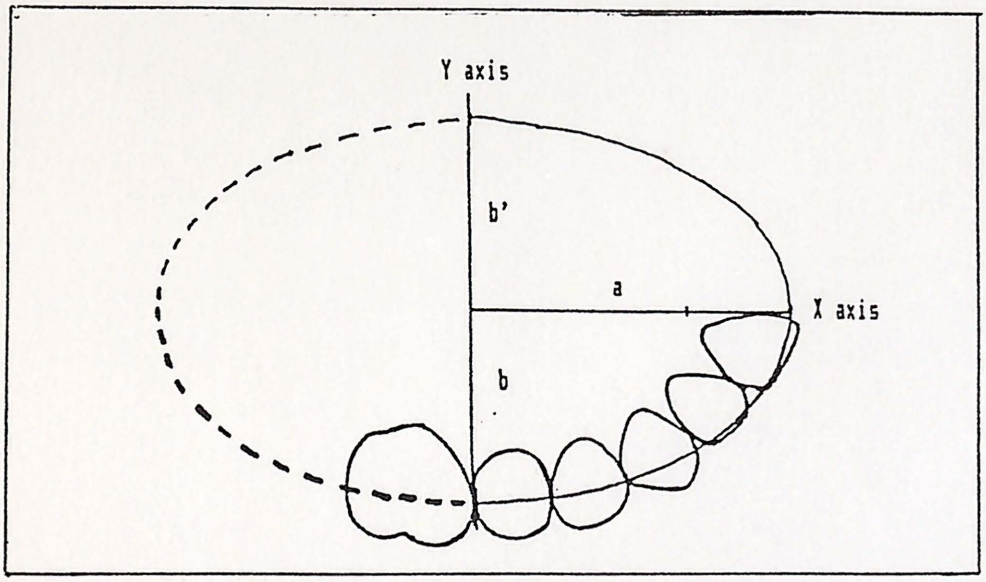
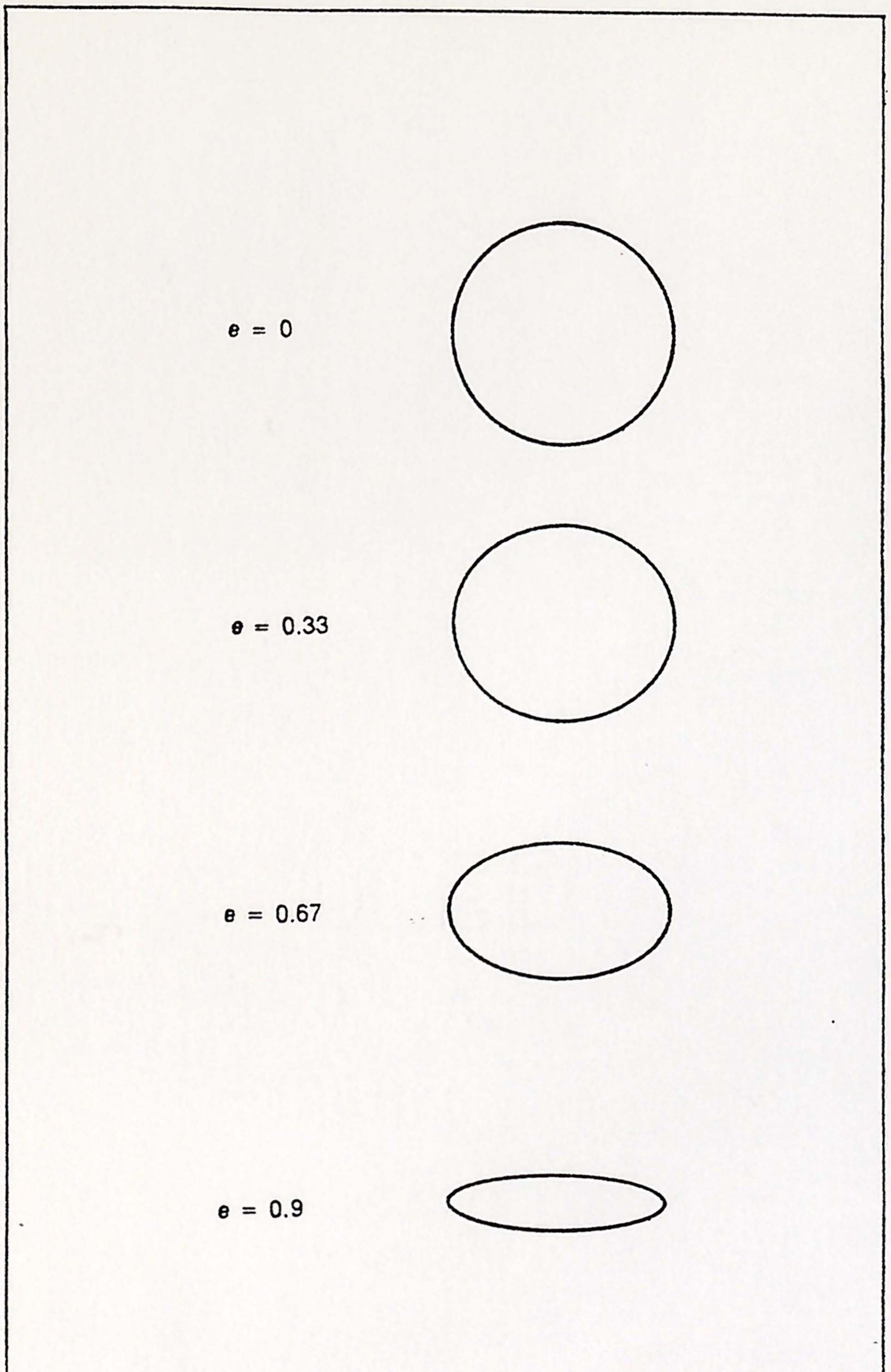
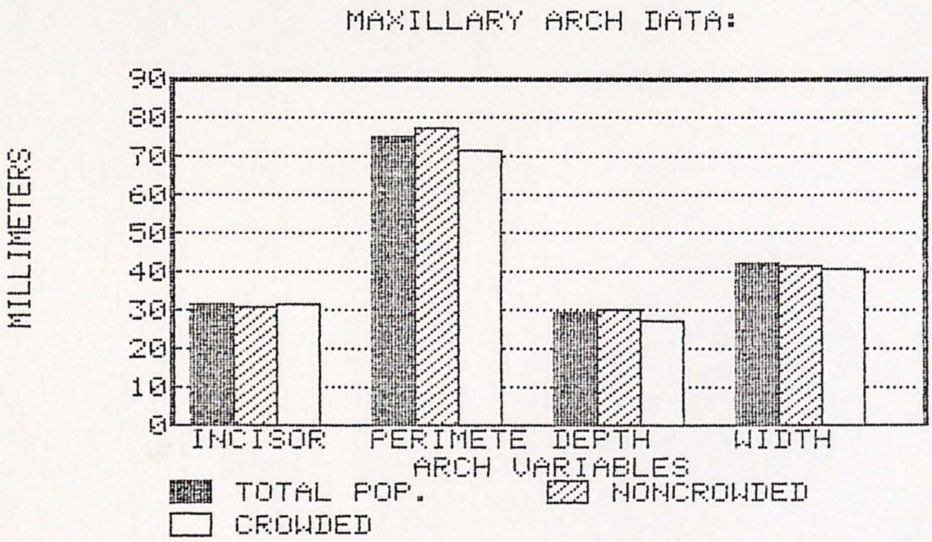

Y axis
b'
a
X axis
b

Figure 8. The eccentricity of an ellipse is a numerical value that describes the shape of the ellipse. An ellipse with an eccentricity of zero is the same as a circle. An ellipse with a higher eccentricity value has a flatter shape.



e = 0
e = 0.33
e = 0.67
e = 0.9

Figure 9. Graphic representation of maxillary arch data for total populations, with noncrowded and crowded group mean values for the following variables: Total incisor tooth mass (Incisor); Arch perimeter (Perimeter); Arch depth (Depth); and Arch width (Width).



MAXILLARY ARCH DATA:
MILLIMETERS
90
80
70
60
50
40
30
20
10
0
INCISOR
PERIMETE
DEPTH
WIDTH
ARCH VARIABLES
TOTAL POP.
NONCROWDED
CROWDED

Figure 10. Graphic representation of maxillary arch data for total population, with noncrowded and crowded group mean values of the following variables: Arch eccentricity (Eccentri); Arch symmetry (Symmetry); Ratio of total incisor tooth mass to arch width (M/W); and Ratio of arch width to arch perimeter (W/P).

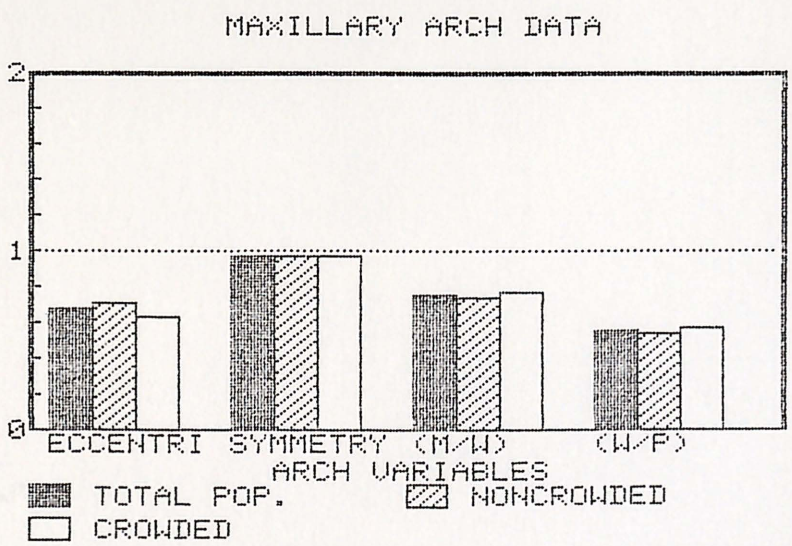

MAXILLARY ARCH DATA
2
1
0
ECCENTRI
SYMMETRY
(M/W)
(W/P)
ARCH VARIABLES
TOTAL POP.
NONCROWDED
CROWDED

Figure 11. Graphic representation of mandibular arch data for total population, with noncrowded and crowded group mean values for the following variables: Total incisor tooth mass (Incisor); Arch perimeter (Arch per); Arch depth (Depth); and Arch width (Width).

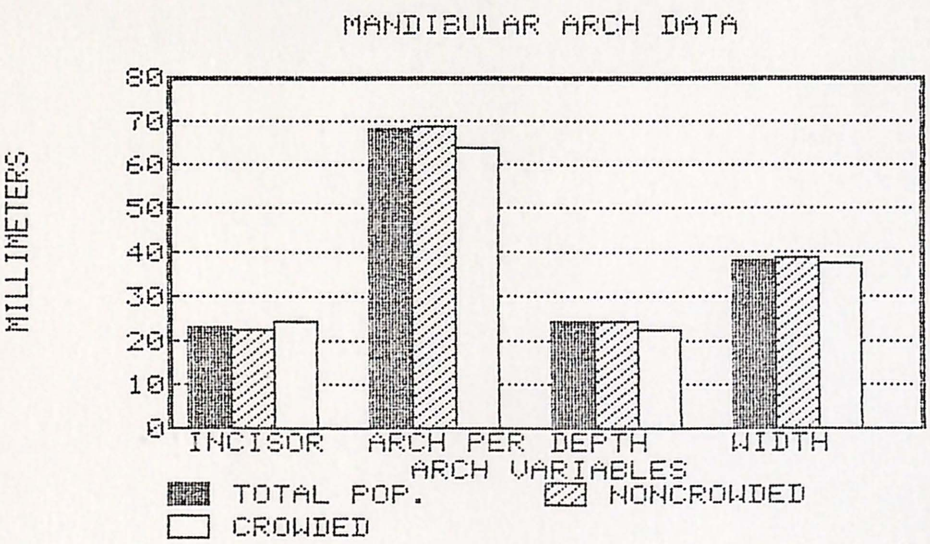

MANDIBULAR ARCH DATA
MILLIMETERS
80
70
60
50
40
30
20
10
0
INCISOR
ARCH PER
DEPTH
WIDTH
ARCH VARIABLES
TOTAL POP.
NONCROWDED
CROWDED

Figure 12. Graphic representation of mandibular arch data to total population, with noncrowded and crowded group mean values for the following variables: Arch eccentricity (Eccentri); Arch symmetry (Symmetry); Ratio of total incisor tooth mass to arch width (M/W); and Ratio of arch width to arch perimeter (W/P).

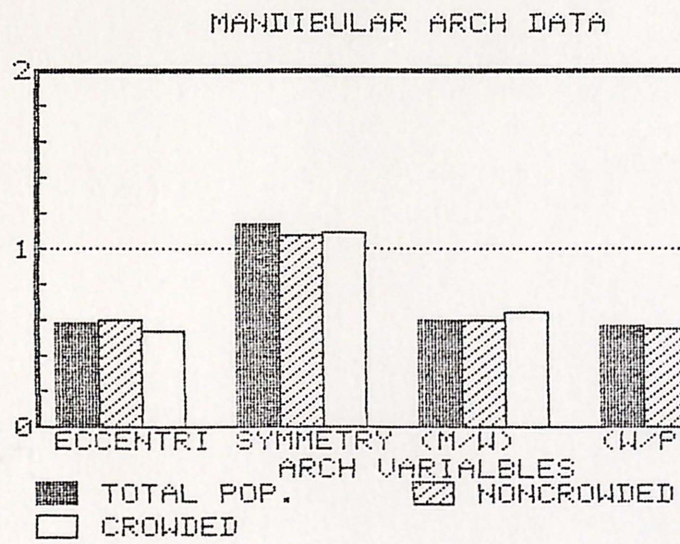

MANDIBULAR ARCH DATA
2
1
0
ECCENTRI
SYMMETRY
(M/W)
(W/P)
ARCH VARIALBLES
TOTAL POP.
NONCROWDED
CROWDED

TABLE I

Means and standard deviation of Moyers' analysis data by computer and by hand calculations. (n = 80)

Moyers' Analysis	Computer	Hand Calc.
Maxillary arch	-1.493 (4.69)	-1.493 (4.69)
Mandibular arch	0.398 (4.51)	0.398 (4.51)

Student's distribution: t = 0.

Coefficient of correlation between replicates: r = 1.

TABLE II

Population description: Description of patients from James Whitcomb Riley Hospital for Children, Dental Clinic, and Department of Pediatric Dentistry, Indiana University School of Dentistry.

Total sample size: 80
Mean age: 115.56 months
Range: 64-163 months

Total white: 60
White male: 28
White female: 32

Total black: 20
Black male: 7
Black female: 13

Maxillary Arch	Noncrowded (n = 54)	Crowded (n = 26)
White male	19	9
White female	17	15
Black male	6	1
Black female	12	1

Mandibular Arch	Noncrowded (n = 69)	Crowded (n = 11)
White male	25	3
White female	27	5
Black male	6	1
Black female	11	2

TABLE III

Mean and standard deviation of the total population value for maxillary and mandibular arch variables. (n = 80)

Variable	Maxillary	Mandibular
Total tooth mass	31.57 (2.00)	23.19 (1.44)
Central incisors	8.84 (0.53)	5.52 (0.37)
Lateral incisors	6.94 (0.57)	6.07 (0.39)
Arch perimeter	75.45 (5.09)	68.19 (3.97)
Arch depth	29.45 (2.84)	24.53 (2.07)
Arch width	42.56 (5.96)	38.61 (2.28)
Eccentricity	0.69 (0.09)	0.59 (0.09)
Symmetry (r/1)	0.97 (0.09)	1.14 (0.51)
Ratio (mass/width)	0.76 (0.06)	0.61 (0.05)
Ratio (width/parim)	0.56 (0.04)	0.57 (0.04)

TABLE IV

Means and standard deviations of the comparison of noncrowded and crowded groups for the maxillary and mandibular arches.

Maxillary Arch	Noncrowded (n = 54)	Crowded (n = 26)
Total tooth mass	31.31 (2.16)	32.09 (1.54)
Central incisors	8.84 (0.53)	8.93 (0.47)
Lateral incisors	6.94 (0.57)	7.12 (0.41)
Arch perimeter	77.36 (4.56)	71.49 (3.68)
Arch depth	30.45 (2.53)	27.42 (2.33)
Arch width	41.45 (5.99)	41.41 (3.20)
Eccentricity	0.72 (0.06)	0.64 (0.12)
Symmetry	0.97 (0.05)	0.98 (0.15)
Ratio (mass/width)	0.74 (0.07)	0.77 (0.05)
Ratio (width/perimeter)	0.55 (0.03)	0.58 (0.04)

Mandibular Arch	Noncrowded (n = 69)	Crowded (n = 11)
Total tooth mass	22.94 (1.19)	24.74 (1.89)
Central incisor	5.47 (0.33)	5.86 (0.45)
Lateral incisor	6.00 (0.33)	6.50 (0.51)
Arch perimeter	68.87 (3.52)	63.99 (4.19)
Arch depth	24.64 (1.85)	22.63 (1.58)
Arch width	38.77 (2.27)	37.64 (2.21)
Eccentricity	0.61 (0.08)	0.54 (0.10)
Symmetry	1.08 (0.19)	1.10 (0.17)
Ratio (mass/width)	0.60 (0.05)	0.66 (0.05)
Ratio (width/perimeter)	0.56 (0.03)	0.59 (0.04)

TABLE V

Statistical analysis of data: Maxillary arch analysis of comparison of noncrowded and crowded arches for significant differences in arch characteristics.

Variable	t	Degrees of Freedom	Level of Significance
Total mass	2.36	25	0.05
Central	1.51	25	NS
Lateral	3.21	25	0.01
Perimeter	-5.87	25	0.01
Arch depth	-6.59	25	0.01
Arch width	-0.063	25	NS
Eccentricity	-3.48*	25	0.01
Symmetry	0.345*	25	NS
Ratio (T/W)	3.00	25	0.01
Ratio (W/P)	3.90	25	0.01

* Denotes a two tail test for significance.

NS Not significant.

TABLE VI

Statistical analysis of data: Mandibular arch analysis for comparison of noncrowded and crowded arches for significant differences in arch characteristics.

Variable	t	Degrees of Freedom	Level of Significance
Total mass	3.16	10	0.01
Central	2.85	10	0.01
Lateral	3.27	10	0.01
Perimeter	-3.84	10	0.01
Arch depth	-4.19	10	0.01
Arch width	-1.67	10	NS
Eccentricity	-2.33*	10	0.05
Symmetry	0.04*	10	NS
Ratio (T/W)	3.75	10	0.01
Ratio (W/P)	2.48	10	0.01

* Denotes a two tail test for significance.

NS Not significant.

TABLE VII

Comparison of the Indiana sample to the Center for Human Growth and Development sample at the University of Michigan (average of 9-10 year values).

Variable	Mean (Standard Deviation) Indiana	CHGD	t	Analysis df = 60 (p 0.01)
Max. central	8.84 (.53)	8.75 (.76)	1.59	NS
Max. lateral	6.94 (.57)	6.92 (.66)	0.31	NS
Mand. central	5.52 (.37)	5.50 (.49)	0.48	NS
Mand. lateral	6.07 (.39)	5.95 (.52)	2.72	S
Max. width	42.56 (5.96)	40.82 (2.35)	2.61	NS
Mand. width	38.61 (2.28)	40.79 (1.93)	-8.54	S
Max. depth	29.47 (2.84)	30.08 (2.01)	-1.92	NS
Mand. depth	24.53 (2.07)	26.12 (1.35)	-6.88	S
Max. perim.	75.45 (5.09)	74.23 (3.50)	2.14	NS
Mand. perim.	68.19 (3.97)	67.14 (2.48)	2.36	NS

A two tail test for significance was performed.

NS Not significant.
S Significant.

TABLE VIII

Error analysis of measurements, time 1: mean and standard deviation, and standard error of individual data measurements of cast analysis (n = 10).*

Variable	Mean	Standard Deviation	Standard Error
23	6.18	0.41	0.13
24	5.52	0.36	0.11
25	5.57	0.38	0.12
26	6.26	0.38	0.12
K-M	22.08	2.24	0.71
23-24	10.93	1.89	0.59
25-26	10.43	1.44	0.46
R-T	22.68	1.18	0.37
7	6.95	0.91	0.29
8	9.01	0.62	0.19
9	8.91	0.56	0.18
10	6.96	0.84	0.26
A-C	22.06	1.35	0.43
7-8	16.25	1.87	0.59
9-10	15.73	1.66	0.52
H-J	22.27	1.06	0.34
Max. Depth	29.77	1.85	0.58
Max. Right Width	20.70	1.40	0.44
Max. Left Width	19.68	1.89	0.59
Mand. Depth	23.68	1.61	0.51
Mand. Right Width	18.45	0.94	0.29
Mand. Left Width	19.11	1.66	0.53

* All measurements are in millimeters.

TABLE IX

Error analysis of measurements, time 2: mean and standard deviation and standard error of individual data measurements of cast analysis (n = 10).*

Variable	Mean	Standard Deviation	Standard Error
23	6.16	0.45	0.14
24	5.51	0.39	0.12
25	5.52	0.41	0.13
26	6.20	0.37	0.12
K-M	22.15	2.01	0.66
23-24	11.43	0.86	0.27
25-26	11.07	1.02	0.32
R-T	22.33	0.96	0.31
7	6.90	0.80	0.25
8	8.92	0.64	0.20
9	8.90	0.69	0.22
10	7.12	0.85	0.27
A-C	22.04	1.39	0.44
7-8	15.81	1.77	0.56
9-10	15.70	1.74	0.55
H-J	22.01	0.94	0.29
Max. Depth	30.42	2.07	0.65
Max. Right Width	20.75	1.49	0.47
Max. Left Width	19.92	1.77	0.56
Mand. Depth	23.73	1.46	0.46
Mand. Right Width	18.67	0.95	0.30
Mand. Left Width	19.66	1.45	0.46

* All measurements are in millimeters.

TABLE X

Error analysis of measurements: Mean, standard deviation, standard error, and error of a single measurement, of the absolute difference between measurements made at time 1 and time 2.

Variable	Mean	(Random Error) Standard Deviation	Standard Error	Error of a Single Measure
23	0.08	0.07	0.25	0.05
24	0.07	0.08	0.026	0.06
25	0.07	0.11	0.33	0.08
26	0.16	0.14	0.045	0.10
K-M	0.17	0.22	0.07	0.16
23-24	0.46	1.04	0.33	0.74
25-26	0.86	1.49	0.47	1.05
R-T	0.51	0.67	0.21	0.47
7	0.17	0.18	0.056	0.13
8	0.11	0.14	0.046	0.10
9	0.13	0.17	0.054	0.12
10	0.21	0.18	0.057	0.13
A-C	0.10	0.16	0.049	0.11
7-8	0.68	0.83	0.26	0.59
9-10	0.59	0.44	0.14	0.31
H-J	0.26	0.36	0.11	0.25
Max. Depth	0.83	0.71	0.23	0.50
Max. Right Width	0.41	0.45	0.14	0.32
Max. Left Width	0.40	0.39	0.12	0.28
Mand. Depth	0.43	0.46	0.14	0.32
Mand. Right Width	0.46	0.31	0.099	0.22
Mand. Left Width	0.73	0.54	0.17	0.38

TABLE XI

Error analysis: Statistical analysis of differences in measurements between time 1 and time 2, utilizing the students' t test and index of reliability.

Variable	t	Index of Reliability
23	-0.14	.98
24	-0.08	.97
25	-0.39	.96
26	-0.52	.92
K-M	0.11	.99
23-24	1.84*	.83
25-26	1.99*	.28
R-T	-1.15	.82
7	-0.20	.97
8	-0.45	.97
9	-0.045	.96
10	0.59	.97
A-C	-0.045	.99
7-8	-0.78	.90
9-10	-0.055	.96
H-J	-0.88	.96
Max. Depth	0.99	.93
Max. Right Width	0.11	.95
Max. Left Width	0.42	.97
Mand. Depth	0.11	.95
Mand. Right Width	0.73	.94
Mand. Left Width	1.19	.94

* Significant difference at $p < 0.01$ using a two tail test.

DISCUSSION

The programs developed for the analysis of the mixed dentition of this study are examples of how the personal computer can enhance the provision of dental treatment and research. The versatility of the microcomputer depends on the availability of a variety of software programs specifically developed for dentistry, without which computers will have little impact on dental care. Developing a software program costs up to five times that of an existing commercially available program.[36] Although there are programs available commercially, they may or may not be able to meet the dentist's computer needs.[147]

The prototype program developed for this study is diagnostic software for the dental profession that is written and tested (debugged), and shown to be accurate. The program utilizes the usual computer system and does not require additional expensive peripheral equipment, such as a digitalizing pad or electric calipers. Such peripheral equipment is not standard and would, therefore, prohibit the general use of diagnostic applications to the office setting. By utilizing the keyboard entries of data measurements, this program can be applied immediately. The dental practitioner need not invest in additional computer equipment or wait for equipment to be installed. The program is versatile and can easily be modified to specific needs, as exemplified by the utilization of the prototype program for the research portion of this study.

A computerized diagnostic program could be considered a central system capable of being modified by other possible modification programs or subsystems.[34] The prototype program, "Moyers' analysis for arch length determination in the mixed dentition adapted for the Apple II personal computer," contains three major components or subsystems in its composition. The major component is arch length analysis at the 75 percent probability level. The second component is computer-assisted instruction for the practitioner, and the third is computer-assisted instruction for the parents and patient on the importance of the primary teeth.

Cast analysis is required for all potential interceptive orthodontic patients, whether the problem is moderate or severe.[9] The obvious advantages of computer arch length analysis are the time savings, accuracy of mathematical calculations, and the production of a permanent record. The time required to enter the initial data measurements into the computer to generation of the printout is under five minutes. The use of the program could allow the dentist to delegate the actual entry of data points into the computer to other office personnel. This would allow the dentist more time with patients and less time on the everyday business aspects of the practice. The printout could become a part of the patient's record, or a copy could be given to the patient's parents as part of the treatment plan presentation.

The report of the Carnegie Commission on Higher Education[148] noted that computer-assisted instruction will be one of the new technologies which hold out the greatest prospects in the long run. The basic subject matter of mixed dentition analysis is well-suited to an individual mode of instruction, such as a computer-assisted instructional tutorial.[149] There are several advantages of using computer programs in patient education: 1) Dental office personnel need not be present for the instruction; 2) the program can be utilized outside of the dental operatory or office in school educational programs; 3) computer programs are not impatient or critical, allowing the students to progress at their own rate; and 4) most children and adults find computer-assisted instruction enjoyable.[150] The subprogram routines on computer-assisted instruction about the importance of the primary teeth, therefore, should find clinical application in the busy dental office.

Modifications of the prototype program were utilized to analyze crowding and its relationship to tooth size, arch dimension, and arch form in the mixed dentition. A comparison of the crowded and noncrowded groups has demonstrated significant differences in values of arch variables between the two groups. Dental space deficiency was correlated with large total incisor tooth mass in both the maxillary and mandibular arches. The findings of this study are in agreement with those of Doris and coworkers,[76] Fastlicht,[151] Norderval and colleagues,[152] and Landstrom.[100] Doris and coworkers[76] examined orthodontic records of 80 subjects who were placed into groups according to the amount of crowding present. Group I had up to 4 mm of crowding, and Group II had more than 4 mm of crowding. Means and standard deviations for each tooth in the maxilla and mandible, exclusive of the molars, were presented. In each case significant differences were found in mesiodistal tooth dimensions between the crowded and noncrowded groups. Fastlicht[151] found a significant correlation between the mesiodistal widths of the maxillary and mandibular incisors and dental crowding. Norderval and colleagues,[152] studying mandibular anterior crowding in a sample of 27 adults with ideal arches and a sample of 39 adults with moderate to mild mandibular crowding, concluded that in the crowded group the four mandibular incisor teeth had significantly larger mesial-distal diameters. Landstrom[100] stated that persons with larger teeth are more likely to have crowding than those with small teeth. The results of this study contradict the findings of Howe and coworkers[103] and Mills.[101] Howe and coworkers[103] selected 104 nonrandom cases and divided groups based on dental crowding. They concluded that tooth size in crowded dental arches could not be distinguished statistically from that in subjects with normal occlusions. Mills[101] stated that little variation existed between crown diameters of persons with and without malalignment.

Significant differences were found in dental alveolar arch perimeter measurements for both the maxillary and mandibular arches when comparing the noncrowded and crowded groups. Arch perimeters are significantly smaller in crowded cases. This is in agreement with Howe and coworkers[103] and Landstrom.[100] Hooten[71] has suggested that dental crowding may result from an evolutionary trend toward a reduced facial skeleton size without a corresponding reduction in tooth dimension. Brash[74] emphasized that a reduction in full expression of facial bone growth and smaller jaws were related to the modern refined diet which played a role in reducing muscular stimulation of the bone.

This study's arch depth measurements are statistically greater in noncrowded individuals than in crowded individuals. No significant differences were found in dental arch width measurements for both the maxillary and mandibular arches between the noncrowded and crowded cases. Frohlich[153] compared the intercanine and intermolar widths of both arches from 51 children with Class II malocclusion with data collected by Moorrees[53] from children with normal occlusion, and found that the absolute arch widths of the two groups did not differ appreciably. Findings of the current study contradict the findings of Staley and others,[137] Howe and colleagues,[103] and McKeown.[102] These investigators found that arch width and crowding were strongly correlated, and that adults with normal occlusion had larger arch widths than subjects with malocclusions.

No significant differences were found in dental arch symmetry measurements for both the maxillary and mandibular arches between the crowded and noncrowded cases. These findings agree with Hechter,[154] who found no significant differences in symmetry between individuals with normal "acceptable" occlusions and individuals with malocclusions. Both groups in his study exhibited some asymmetries of arch form, regardless of occlusal type. This agrees with the findings of Landstrom,[155] Lebret,[156] Stabb,[157] and Vincent.[158] Dental arch symmetry was also found to be randomly distributed and independent from Angle's malocclusion classification. However, Howe and others[103] reported that noncrowded arches were uniform in shape with broad symmetrical arch forms, while crowded arches were sometimes asymmetrical and strikingly irregular in arch form.

Previous investigators who have commented on arch form have utilized linear dimensions in their descriptions. Most studies of arch form use the ellipse, the catenary curve, and the polynomial equation to the sixth power as it related to the "goodness of fit." Musich and Ackerman[159] and Hechter[154] suggest that if the arch form is going to be assessed only from first molar to contralateral first molar, it is not important which curve form is utilized as the "mean curve." The current study used the ellipse as the basis of arch form and described its shape by the eccentricity value. The sample mean value of the eccentricity of the ellipse was 0.69 for the maxillary arch, with significant differences between crowded and noncrowded groups in eccentricity values. The mandibular arch mean value was 0.59, with significant differences between crowded and noncrowded groups. The noncrowded groups had larger eccentricity values than crowded groups. An ellipse with a higher eccentricity value has a flatter or narrower shape. However, Howe and others[103] noted that crowded arches were frequently narrower or more tapered than non-crowded arches. Shapiro[160] obtained inconclusive results in a study to describe and quantify the changes in mandibular arch form at pre-orthodontic treatment, end of treatment, and postretention stages, utilizing a computer to determine the best-fitting catenary curve of each mandibular arch.

Since similar studies using the eccentricity of an ellipse to assess arch form do not exist, it is impossible to make statistical comparisons to other investigations. However, utilizing the linear dimensions or plotted scattergram data of arch form it is possible to mathematically calculate eccentricity values from results of these studies. Dummett[161] compared palatal vault form in maxillary arch dimension in cerebral palsy children. The control group of 76 subjects were randomly selected from children seeking dental treatment in the Undergraduate Division of Pediatric Dentistry of Indiana University School of Dentistry. The eccentricity value for Dummett's control group was 0.70 for the maxillary arch. The current study utilized the same geographic area for the patient pool and had an overall eccentricity of 0.69 for the maxillary arch. Hechter[154] in studying the symmetry and dental arch form of orthodontically treated patients produced plotted scattergram arch forms, which were utilized to calculate eccentricity values. The maxillary arch and mandibular arches both had values of 0.65. Sampson,[105] utilizing the Center for Human Growth and Development data for 3-18 year olds, developed a sample model arc, an average dental arch shape whose eccentricity value could be calculated as 0.71. MacConaill and Scher[113] investigated the catenary curve. Utilizing scattergrams of the mean occlusal points of 50 subjects, the following eccentricity values could be calculated: maxillary arch eccentricity of 0.77, and mandibular arch eccentricity value of 0.71. Younes[162] studied maxillary arch dimensions in Saudi and Egyptian population samples. Calculations from the linear measurements of arch dimension yielded an eccentricity value of 0.56 for the Saudi population and 0.54 for the Egyptian subjects. Howe and others,[103] in analyzing dental crowding and its relationship to tooth size and arch dimension, presented representative cases of crowding and noncrowding. Noncrowded cases had calculated eccentricity values of 0.63 for the maxillary arch and 0.57 for the mandibular arch. Crowded cases had calculated eccentricity values of 0.71 for the maxillary arch and 0.63 for the mandibular arch.

The eccentricity of an ellipse appears to be a clinically useful value. This value may be used to demonstrate variations in arch form based on crowded and noncrowded cases, as shown by this study and the values calculated from other studies. Also, the eccentricity value may be used to describe differences in arch shapes between races. The Indiana subjects are in agreement, but are different in value from the Saudi and Egyptian (Middle Eastern) populations.

For the current study the index of crowding values was defined as the ratio of the sum of the incisor tooth widths to the arch width (T/W). A significant difference was found between the values of this ratio for both maxillary and mandibular crowded and noncrowded arches. The ratio was larger in crowded individuals, reflecting the larger tooth size found in this group. Howes[163] devised a formula for determining whether the apical bases of the patient could accommodate the patient's teeth. This formula was based upon total tooth mass and the arch width at the tip of the buccal cusps of the first premolars. Howes[163] stated that the premolar basal arch width should equal approximately 44 percent of the mesiodistal widths of the 12 teeth in the maxilla if it is to be sufficiently large to accommodate all of the teeth. Since the current study was conducted during the early-middle mixed dentition, the permanent mesiodistal widths of all teeth were unknown, but could have been estimated by Moyers' analysis. However, a decision was made to utilize only known tooth sizes; therefore, the index of crowding comprised only the four incisors. Howes'[163] analysis is the inverse of the ratio used in the current study, so that direct comparison is not possible. Pont[164] developed an index for relating the sum of the maxillary incisors to the dental arch width. The analysis can be used for both arches. Mathematically, it is expressed as: A = (SI) X 100/64 where "A" is the distance necessary for cross-arch width at the maxillary first molar measured at the central fossa of each first molar, and "SI" is the sum of the incisors in millimeters. Again, no direct correlation of data with this study can be made. The ratio of arch width to arch perimeter (W/P) was found to be significant in the values for both maxillary and mandibular crowded and noncrowded arches. The ratio was larger in crowded individuals, reflecting the smaller arch perimeter found in the crowded group.

This study suggests that dental crowding is associated with both small dental arches and large teeth. Therefore, greater consideration may be given to treatment techniques which increase dental arch width, length, and perimeter. This is especially relevant in younger patients whose dentitions are in the deciduous and mixed stages of development.[103]

Most malocclusions normally do not self-correct with age or facial growth. When Hunter and Smith[165] looked at the degree of dental crowding and its relation to age, crowding at age nine showed a high correlation with crowding at age 16. Kussick[166] suggested that most malocclusions in the early mixed dentition develop because of poor integration between developing alveolar bone and the morphology and anatomic relationship of the mandible and maxilla. Moorrees and coworkers[167] have shown that in the average child arch length decreases with age, especially in the mandible. Therefore, if a younger patient in the mixed dentition demonstrates dental crowding with small dental arches, treatment measures may include efforts to augment jaw development in order to accommodate the existing tooth mass.[101] This may be accomplished by early expansion procedures using such appliances as the rapid palatal expander, Frankel appliances,[168] other functional orthopedic appliances, and bone remodeling therapy utilizing an acrylic bone remodeler.[166] These appliances and procedures could be used alone or in combination with other forms of therapy. Correction of many malocclusions is facilitated by beginning treatment in the mixed dentition; however, it is sometimes necessary to follow such treatment by traditional orthodontic therapy once all the permanent teeth have erupted.[69]

SUMMARY AND CONCLUSIONS

The programs developed in this study are examples of how a personal computer can aid the delivery of dental care. The versatility of the computer depends on the availability of a variety of programs specifically developed for dentistry, without which computers will have little impact on treatment. Moyers' analysis adapted for the Apple II, and its research modification are computer programs developed specifically for dentistry.

Accurately predicting the mesiodistal widths of the unerupted permanent canines and premolars in the mixed dentition can lead to orthodontic treatment that is optimally timed, with desirable facial and dental results.[64] The stage of the mixed dentition constitutes the most intricate period in the development of the occlusion; any small anomaly occurring in this stage can pose complicated problems for the permanent dentition, requiring a more extensive and expensive mechanotherapy.[70] Malocclusion is a developmental problem.[9]

Analysis of dental crowding and its relationship to tooth size and arch dimensions yielded the following results for the maxillary and mandibular arches:

1. Statistically different values for tooth size were noted between crowded and noncrowded groups, with crowded individuals having larger teeth.
2. Arch perimeter and arch depth were significantly smaller in crowded groups than noncrowded groups.

3. No significant differences were noted between crowded and noncrowded groups in arch width or symmetry.
4. Significant differences were demonstrated in the eccentricity value of an ellipse for crowded and noncrowded cases.

This study suggests that dental crowding is associated with both small dental arches and large teeth. Therefore, greater consideration may be given to those treatment techniques which increase dental arch width, length, and perimeter. This is especially relevant in younger patients whose dentitions are in the deciduous and mixed stages of development.[103]

Further investigation into the relationship of dental crowding and arch shape with a larger sample might be productive. The eccentricity of a curve should be used to evaluate pre and post orthodontic treatment. Modifications to the basic computer program could include prediction values for Black Americans,[169] cephalometric value interpretation, and the Bolton and Ponts analysis as a comprehensive diagnostic computer package.

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APPENDIX

PROGRAMMER'S NOTES: OPERATING INSTRUCTIONS FOR MIXED DENTITION ANALYSIS FOR THE APPLE PERSONAL COMPUTER

A few notes on "Moyers' Analysis for the Apple II Computer." The program is written in "Applesoft," and will only run on Apple computers with this language capability. The program is also written for 80 column display and, therefore, requires and 80 column card and 128 K of memory. The program is designed to be "user-friendly" and utilizes a "one step" disk boot.

OPERATING INSTRUCTIONS

1. Turn off the computer.
2. Insert the diskette into the disk drive.
3. Turn on the computer.
4. The program will automatically "boot" itself.
5. The "Caps Lock" key and your printer are ON.
6. While entering data, be advised that the computer will not accept punctuation marks, such as commas and periods. It will accept decimal places for numerical entries.

Unfortunately, the program will not measure your casts. This still must be completed by hand, but the computer will quickly do the mathematics required in the diagnosis of space adequacy or loss.

<u>Users of this program please note the following:</u>

1. This program's performance may not meet your requirements for this analysis.
2. There is no guarantee that the program's operation will be error-free.
3. The programmer accepts no liability for any direct, consequential, or incidental damage that may result from the usage of this program.
4. The user accepts all liabilities in that regard, and each analysis should be evaluated by the user for its accuracy and applicability.

The program, "Moyers' Analysis for the Apple II Computer," is designed to automatically subtract for loss of the "leeway" space in its calculations for space availability. If you do not desire the loss of "leeway" space in your calculation, please make the following program line changes by retyping in the following after loading MIXED DENTITION ANALYSIS:

```
3972 UL = U - Z
3974 UR = T - Z
3796 LL = W - X
3798 LR = V - X
```

If after using the program, you desire to by-pass the two introductory programs and go directly to "MIXED DENTITION ANALYSIS," simply change program line 120 of the "HELLO" program to the following:

```
120 PRINT CHR$ (4); "RUN MIXED DENTITION ANALYSIS"
```

The printer instructions were designed for the Epson Standard Dot Matrix Printer or comparable models. If you encounter difficulty with the printout, please consult your printer command list and alter the program appropriately.

CURRICULUM VITAE

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May 3, 1955	Born in Fort Thomas, Kentucky.
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ABSTRACT

COMPUTER-ASSISTED ANALYSIS OF DENTAL CROWDING AND ITS RELATIONSHIP TO TOOTH SIZE, ARCH DIMENSION, AND ARCH FORM IN THE MIXED DENTITION, UTILIZING THE APPLE II PERSONAL COMPUTER

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The programs developed in this study are examples of how a personal computer can aid the delivery of dental care. The versatility of the computer depends on the availability of a variety of programs specifically developed for dentistry, without which computers will have little impact on treatment. Moyers' analysis adapted for the Apple II and its research modification are computer programs developed specifically for dentistry.

Accurately predicting the mesiodistal widths of the unerupted permanent canines and premolars in the mixed dentition can lead to orthodontic treatment that is optimally timed, with desirable facial

and dental results. The stage of the mixed dentition constitutes the most intricate period in the development of the occlusion; any small anomaly occurring in this stage can pose complicated problems for the permanent dentition, requiring a more extensive and expensive mechanotherapy. Malocclusion is a developmental problem.

Analysis of dental crowding and its relationship to tooth size and arch dimensions yielded the following results for the maxillary and mandibular arches:

1. Statistically different values for tooth size were noted between crowded and noncrowded groups, with crowded individuals having larger teeth.
2. Arch perimeter and arch depth were significantly smaller in crowded groups than noncrowded groups.
3. No significant differences were noted between crowded and noncrowded groups in arch width or symmetry.
4. Significant differences were demonstrated in the eccentricity value of an ellipse for crowded and noncrowded cases.

This study suggests that dental crowding is associated with both small dental arches and large teeth. Therefore, greater consideration may be given to those treatment techniques which increase dental arch width, length, and perimeter. This is especially relevant in younger patients whose dentitions are in the deciduous and mixed stages of development.

Further investigation into the relationship of dental crowding and arch shape with a larger sample might be productive. The eccentricity of a curve should be used to evaluate pre and post orthodontic treatment. Modifications to the basic computer program could include prediction values for Black Americans, cephalometric value interpretation, and the Bolton and Ponts analysis as a comprehensive diagnostic computer package.